8. Overview of Hurricane Katrina in the New Orleans Area

FEMA was particularly interested in the long-duration impacts of flooding on buildings in New Orleans as well as the floodplain management issues surrounding the levee breaches. The New Orleans Flood Team conducted ground inspections throughout the New Orleans area, including the City of New Orleans and Orleans Parish, as well as the nearby communities of Chalmette in St. Bernard Parish and Metairie in Jefferson Parish.

The Flood Team visited a total of 23 residential buildings and critical and essential facilities in the New Orleans area from October 4 to 8, 2005 (see Figure 8-1). The focus of the site inspections was to assess flood damage to residential buildings and critical and essential facilities, and evaluate opportunities for flood restoration. The Flood Team's investigation showed that structural damage to buildings was localized to certain areas, and that the most significant damage was from long-duration flooding of non-structural building components related to saturation of porous building materials with contaminated water.

Figure 8-1. Residential buildings and critical and essential facilities visited by the New Orleans Flood Team. (Due to the map scale, some sites are not included on this map.)

Section 8.1 discusses flooding in the New Orleans area. Floodplain management issues related to levees and floodwalls in the New Orleans area, including the history of the New Orleans levee system, and floodplain mapping and building construction within the New Orleans levee-protected area, are presented in Section 8.2. Section 8.3 contains a general characterization of structural and non-structural flood damage. Long-duration flood impacts on buildings, including deterioration of building materials and contamination, are discussed in Section 8.4.

8.1 Flooding in the New Orleans Area

Flooding in most places within the levee/floodwall protected area in and around New Orleans was due to breaches in levees and canals. Pump systems that would normally have removed floodwaters were non-operational due to inundation or from a loss of primary and backup power. In Metairie, flooding was caused by high water from Lake Pontchartrain surcharging the drainage system with pumps off. Local officials decided to evacuate pump operators on August 28 before the storm hit, according to *The Times-Picayune* and first-hand accounts given to the New Orleans Flood Team.

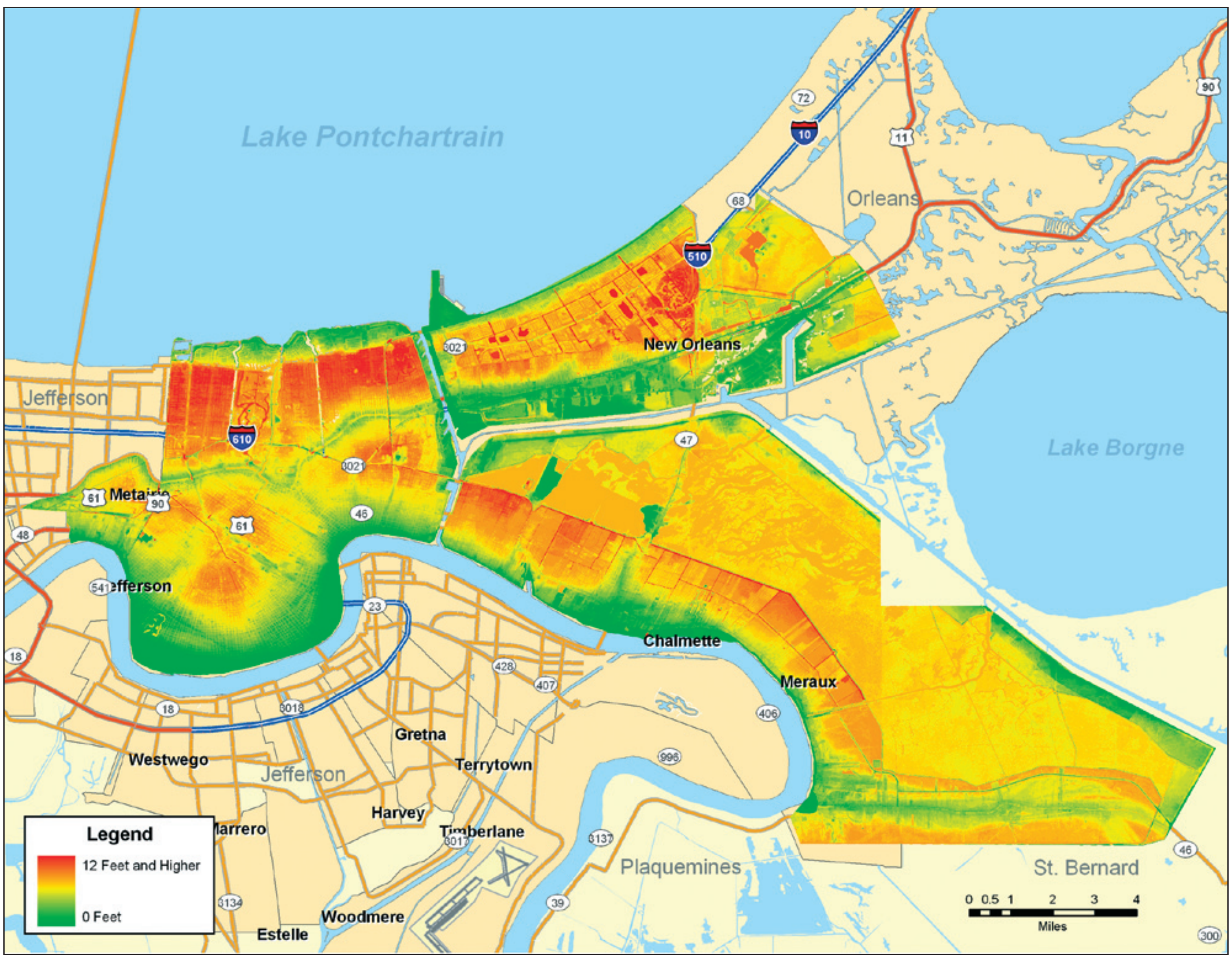

Figure 8-2. Map of estimated flood depths in New Orleans

SOURCE: FEMA

As a result of the levee/floodwall breaches, widespread flood damage to residential neighborhoods occurred throughout the New Orleans area. The depth of flooding within the Greater New Orleans area varied greatly, as did damage to structures. West of the 17th Street Canal, areas of Metairie in Jefferson Parish had shallow flooding, typically less than 1 foot in depth. East of the 17th Street Canal, flood depths in excess of 8 feet were observed in Lakeview on the north side of New Orleans near Lake Pontchartrain, the Lower Ninth Ward, and Chalmette (see Figure 8-2). Floodwaters remained in most New Orleans neighborhoods for approximately 2 to 3 weeks after the levee/floodwall breaches. Areas by the Mississippi River and the high ground along Lake Pontchartrain between the 17th Street Canal and the Industrial Canal were essentially free of flooding. These relatively elevated land areas form parts of the rim of the New Orleans "bowl."

In all areas affected by flooding resulting from Hurricane Katrina, property elevation was the key difference in the magnitude of damage. The higher the property grade elevation, the lower the flood damage. In areas of New Orleans at the same grade elevation, buildings elevated on crawlspaces generally sustained less flood damage than slab-on-grade buildings. In addition, flooding was exacerbated by the long-term subsidence of the New Orleans area, which has resulted in some areas being below sea level. Scientists estimate that the rate of subsidence of Southern Louisiana is as much as 3 feet every 100 years, or a little less than a 1/2 inch per year (*National Geographic News*, "New Orleans — A Man Made Disaster?", October 13, 2005, National Geographic Society, Washington, DC).

8.2 Floodplain Management Issues Related to Levees/Floodwalls in the New Orleans Area

Floodplain mapping in the New Orleans area has historically been based on an assumption that the area was protected by the USACE-certified levee system, which was developed over several decades beginning in the 1920s. This assumption led to floodplain regulations that allowed building construction to occur at or below sea level with no accommodations made for the possibility of riverine or coastal flooding. A detailed discussion of the New Orleans levee system and the floodplain management issues related to the levees/floodwalls is provided in Sections 8.2.1 and 8.2.2, respectively.

8.2.1 History of the New Orleans Levee System

Based on information provided by the New Orleans District of the USACE, the New Orleans levee/floodwall system was constructed in two parts. The first part, the Mississippi River Levee System (MR&T), was designed to protect the city from a flood flow of 3 million cubic feet per second from the Mississippi River, and was constructed under the authority of the Flood Control Act of 1928 and subsequent amendments. The MR&T system in the New Orleans District extends along the west bank of the Mississippi River from the vicinity of Black Hawk, Louisiana, generally southward to the vicinity of Venice, Louisiana, and on the east bank from Baton Rouge, Louisiana, to Bohemia, Louisiana.

The second part of the levee system, the Lake Pontchartrain and Vicinity Hurricane Protection Project (LP&V-HPP), was designed to protect residents between Lake Pontchartrain and the Mississippi River levee from surges in Lake Pontchartrain and Lake Borgne by storms up to a fast-moving Category 3 hurricane. The LP&V-HPP was authorized by the Flood Control Act of 1965, the Water Resources Development Act of 1974, and subsequent amendments. The LP&V-HPP is located in St. Bernard, Orleans, Jefferson, and St. Charles Parishes, generally in the vicinity of the City of New Orleans, and between the Mississippi River and Lake Pontchartrain. The LP&V-HPP system also protects residents from surges in the canals, which extend from Lake Pontchartrain to the south. These canals have been in existence since the late 1800s and were originally designed to provide navigation and drainage of the lowest parts of the City of New Orleans. The LP&V-HPP system is composed of numerous levees and flood walls, including the 17th Street Canal and London Avenue Canal levees/floodwalls.

8.2.2 Floodplain Mapping and Building Construction within the New Orleans Levee-Protected Area

The two-part New Orleans levee/floodwall system was certified by the USACE as providing at least 100-year flood protection, in accordance with the NFIP requirements. Due to this certification, the FIRMs for the area, which are the basis for the flood insurance and floodplain management, did not reflect flooding from the Gulf of Mexico, Lake Pontchartrain, or the Mississippi River. Although the FIRMs did reflect some flooding in the areas protected by the levee/floodwall system, the source of this flooding was not from a levee/floodwall breach, but from rainfall within the protected 'interior' area, generating runoff and producing localized flooding. This interior flooding was to be removed by a network of pumps supported by backup power in the case of major power outages. As a result, the FIRMs showed some of the interior areas either as having no floodplain or with a floodplain reflective of local runoff or ponding and awaiting removal outside the levee/floodwall system by the pumping network.

The 100-year flood elevations, or BFEs, in the interior areas protected by the levee/floodwall system were low compared to the actual flood elevations experienced as a result of Hurricane Katrina. A review of the FIRMs for neighborhoods observed by the New Orleans Flood Team indicated that most of the BFEs were at approximately sea level elevation, with some actually below sea level. This meant that, in areas of New Orleans that were protected by the certified levee/floodwall system, building development could occur below sea level while still being at or above the BFE and compliant with the NFIP.

Examples of the disparity between the BFE as compared to the elevation of the levee/floodwall and the flood elevations observed due to Hurricane Katrina were found in many neighborhoods of the city. Many buildings were newer construction and were fully compliant with the NFIP and the local building code. In many instances, homeowners had added freeboard to elevate their homes higher than the BFE by 1 or 2 feet as added protection from the flood source. They understood they were vulnerable to interior flooding. Yet many of these residential buildings still experienced 3 to 5 feet of flooding above their first floor elevation as a result of the levee/floodwall breach (see Figure 8-3). Homeowners interviewed in these neighborhoods stated that they did not realize that a breach of the levee/floodwall system could allow such major flooding to occur.

Aggravating this issue was the change in building construction techniques in the New Orleans area since the construction of the levee/floodwall system. Historically, New Orleans residential construction often incorporated elevation where the first finished floor was elevated several feet above grade (see Figure 8-4, upper left). The area below the first finished floor was unfinished and was used as a crawlspace or, if high enough, a garage area. When floods occurred, the first finished floor remained dry, the lower unfinished area was easily cleaned after the flood, and flood damages were minimal. More recent New Orleans residential construction has consisted almost exclusively of either slab-on-grade foundations or slight elevations above grade with a minimal crawlspace, both reflecting BFEs based only on local drainage flooding in the protected areas shown on the FIRM (see Figure 8-4, lower right). This recent change in construction techniques, combined with ongoing land subsidence, contributed to the magnitude of flood damage observed in New Orleans.

Figure 8-3.
Residential building constructed approximately 1 foot above the BFE in accordance with current codes. Note flood depths were even with the top of the garage door, or about 3-5 feet above the first floor (red line).

8.3 General Characterization of Flood Damage

As discussed previously, most of the damage observed in the New Orleans area was nonstructural and related to long-duration flood issues; only limited structural damage was observed. Damages to various building types were similar, with no significant difference in impacts observed between residential buildings and critical and essential facilities. Most observed buildings, including residential as well as critical and essential facilities, were constructed on vented crawlspaces or slab-on-grade foundations with wood-framed walls covered by brick veneer.

Figure 8-4.
Comparison of building techniques in New Orleans. The older residence on the upper left has the first finished floor constructed several feet above grade. The newer residence on the lower right is constructed with a slab-on-grade foundation.

8.3.1 Structural Damage

Only minimal structural damage was observed in the majority of buildings in New Orleans as a result of flooding from Hurricane Katrina. There are two primary reasons for this observation. First, the flooding in New Orleans was caused by slow-moving floodwaters, which greatly reduced or eliminated the damaging effects of hydrodynamic forces and floodborne debris impacts on buildings. Second, the crawlspaces, foundation vents, garage bay doors, and other openings allowed hydrostatic pressures on walls and floors from floodwaters to equalize as floodwaters gradually rose and receded, which greatly reduced the net hydrostatic force on load-bearing walls, floors, and other structural elements.

Although flood-related structural damage was typically minor, there were several significant exceptions:

- First, the failure of the Industrial Canal (see Figure 8-5) and coastal levees produced intense flooding in eastern New Orleans and St. Bernard Parish, resulting in severe structural damage in the Lower Ninth Ward of New Orleans and Chalmette in St. Bernard Parish. Observations by the New Orleans Flood team indicated widespread destruction of residential buildings in the Lower Ninth Ward from high velocity floodwaters and strong winds, waves, and high floodwaters that knocked buildings off their foundations, collapsed load-bearing walls, and caused other structural failures.

- Second, residential buildings sited immediately behind failed sections of levees or other flood control structures such as the 17th Street Canal levee breach suffered significant structural damage, failure of load-bearing walls, and excessive scour around slab foundations from large hydrodynamic forces generated by the levee breach (see Figure 8-6). However, these forces and impacts were quickly dissipated within a few blocks of the breach.
- Third, buildings sited on poor foundation soils suffered significant structural damage and cracking of load-bearing walls and sagging floors due to subsidence or differential settlement of saturated soils that support one or more foundation walls and/or piers (see Figure 8-7). While most of the observed structural damages triggered by soil settlement or subsidence did not constitute an imminent danger of collapse, such damages (and the underlying soil problems behind them) typically require analysis by a foundation engineer and can be expensive to isolate and repair.

Figure 8-5. The Industrial Canal levee breach in New Orleans

SOURCE: LSU HURRICANE CENTER

Figure 8-6.
Structural damage to residential buildings (circle) in New Orleans located immediately behind the site of 17th Street Canal levee breach (arrow)

Figure 8-7.
Settlement cracks in upper floor wall of New Orleans residence due to subsidence/differential settlement of underlying foundation soils during long-duration flooding

Visual observations of interior walls of both older (more than 50 years old) and newer (less than 5 years old) residential buildings showed little to no evidence of deterioration of the exposed portions of the structural wall studs due to long-duration flood exposure, except for some water staining and slight bowing of some sheathing boards (see Figures 8-8 and 8-9). However, moisture readings taken inside various residential buildings indicated that excess moisture remained trapped in the walls and floors following the flood. Continued entrapment of moisture within the wall and floor systems due to a lack of drying could induce rotting of the structural framing in the long term.

Figure 8-8.
Exposed wall studs and sheathing boards in 74-year-old New Orleans residential building, showing no significant deterioration from long-duration flooding

Figure 8-9.
Exposed wall studs and sheathing boards in 2-year-old New Orleans residential building, showing no significant deterioration from long-duration flooding.

8.3.2 Non-Structural Damage

Widespread non-structural damage occurred to areas in and around New Orleans that were impacted by long-duration flooding. Unlike other hurricane-impacted areas, where residents could access their buildings relatively quickly after the flood event, the residents of New Orleans who were protected by the levee/floodwall system were unable to access buildings for several weeks because of prolonged flood inundation. As a result, the extent of interior damage was larger than damages observed in previous hurricane events.

Typical flood damages to buildings included damaged or destroyed interior drywall, plaster, fiber insulation, metal studs, flooring, wall finishes, carpets, and furniture (see Figure 8-10). Mold growth observed in flooded residences varied from light to extensive, depending on the depth of flooding, the type of interior wall finishes, and the amount of drying that occurred after the floodwaters receded (see Figures 8-10 and 8-11). Additionally, floodwaters carried bacterial and chemical pollutants into buildings, thereby contaminating porous building materials (refer to Section 8.4.2).

Several fire stations in New Orleans suffered flood damage to garage bay doors (see Figure 8-12). The fire stations in New Orleans observed by the MAT did not contain fire trucks or other heavy equipment; these appear to have been relocated prior to the flood. Many New Orleans hospitals suffered interior damage such as collapsed drop ceilings due to a loss of emergency power generators, which shut down HVAC systems used to control temperature and humidity. In some hospitals, the loss of emergency generators resulted from flooding of the generator controls or the fuel storage tanks (see Figure 8-13). However, in most hospitals, the loss of emergency generators occurred as a result of mechanical breakdown from extended use following Hurricanes Katrina or Rita.

Figure 8-10.
Typical interior flood damage to residential building in New Orleans, showing extensive mold growth (circle)

Figure 8-11.
Typical interior flood damage to residential building in New Orleans, showing light mold growth (compare to Figure 8-10)

Figure 8-12.
Damage to garage bay doors at fire station in New Orleans. The door on the right was pushed in by flooding; the door on the left appears to have been pulled open from the outside by looters.

Figure 8-13. Flooded emergency generator at hospital in New Orleans (note flood line in red)

8.4 Long-Duration Flood Impacts on Buildings

Damage from long-duration exposure to floodwaters often lies concealed within the building envelope and within wall cavities. The level of the water intrusion, the concentration of floodborne contaminants, and the length of time until floodwaters recede are important factors influencing the potential salvagability of building materials and personal property. In general, the long-duration flood damages observed in the New Orleans area were primarily to porous building materials, including wall sheathing, ceilings, and floor coverings. These materials experienced deterioration from being saturated and were impregnated with contaminated floodwater.

In order to examine the effects of long-duration flooding on porous building materials, members of the New Orleans Flood Team conducted field readings and took building material samples for laboratory testing from seven residential buildings and two fire stations in the New Orleans area from October 6 to 8, 2005. The buildings sampled were selected from among the 23 residential buildings and critical and essential facilities visited in the New Orleans area from October 4 to 8, 2005 (Figure 8-1) to reflect a variety of observed flood depths, building types, and potential contamination levels. The sampling undertaken was for informational purposes only and was not intended as a statistical representation of conditions throughout the City. Table 8-1 summarizes the buildings sampled for field readings and laboratory testing. Specific information on the field readings and laboratory tests is provided in Sections 8.4.1.2 and 8.4.2.1.

Table 8-1. Summary of Buildings Sampled and Tests Conducted

Building Sampled	Interior Flood Depth (feet)	Summary of Readings and Tests Conducted			
		Specific Humidity (Section 8.4.1.2)	Material Moisture Contents (Section 8.4.1.2)	Biological Contaminants (Sections 8.4.2.1 and 8.4.2.2)	Chemical Contaminants (Sections 8.4.2.3 – 8.4.2.6)
Residence at Elysian Fields	6.0 - 8.0	✔	✔	✔	✔
Residence at General Diaz Street	6.0 - 7.0	✔	✔	✔	✔
Residence at Memphis Street	6.0	✔	✔	✔	✔
Residence at Savoie Court	0.83 - 1.0	✔	✔	✔	✔
Residence at Munster Boulevard	7.5		✔	✔	✔
Residence at Cleary Avenue	0.83 - 1.0	✔	✔	✔	✔
Residence at Octavia Street	5.5		✔	✔	✔
Fire station at Louisiana Avenue	3.0		✔	✔	✔
Fire station at South Carrollton Avenue	2.0 - 3.0		✔	✔	✔

8.4.1 Deterioration of Building Materials from Long-Duration Flooding

8.4.1.1 Mechanics of Deterioration

In general, differing types of long-duration flood damage occur above and below the high water mark. Above the high water mark, moisture damage occurs as the result of capillary action, water vapor migration, and condensation. Below the high water mark, damage occurs from solvent action, corrosion, waterborne solids, contaminants, and bacterial degradation.

- **Capillary action:** Visual observations of interior walls and other building materials in various residential buildings and critical and essential facilities in the New Orleans area showed evidence of capillary action above the water line. A summary of specific humidity readings taken by the New Orleans Flood Team inside and outside the selected residential buildings is provided in Table 8-2. The specific humidity readings confirmed field observations that the interiors of the homes were consistently wetter than the outdoors and that opening exterior doors and windows would facilitate drying of building materials within homes. Material moisture content readings taken in various residential buildings and critical and essential facilities also showed elevated moisture contents in the drywall and/or plaster in the first floors of the buildings when compared to the upper floors.

- **Water vapor migration:** Visual observations of building materials in various residential buildings and critical and essential facilities in the New Orleans area showed evidence of water vapor migration above the water line. Interior doors and cabinet doors and drawers constructed of laminated wood products and other porous building materials were swollen shut and difficult to open as a result of water vapor migration (see Figure 8-14).

- **Solvent action:** Visual observations of interior walls of both older (more than 50 years old) and newer (less than 5 years old) residential buildings and various critical and essential facilities in the New Orleans area showed little to no evidence of deterioration by solvent action above or below the water line.

- **Corrosion:** Visual observations of metal connectors and electrical components in both older (more than 50 years old) and newer (less than 5 years old) residential buildings and various critical and essential facilities in the New Orleans area showed little to no evidence of deterioration by corrosion above or below the water line. This may be explained by the generally low salinity of the floodwaters that impacted the New Orleans area following Hurricane Katrina.

Capillary action. Capillary action, commonly referred to as "wicking," is the process by which water molecules adhere to surfaces and climb upward through materials against gravity.

Water vapor migration. Water vapor migration through the interior of a building is invisible and often overlooked. Water vapor affects materials such as wood and paper, which increase or decrease in size (i.e., swell or shrink) based on their moisture content.

Solvent action. Water is a powerful and effective solvent and can dissolve some paper products such as drywall (gypsum board) paper.

Corrosion. Metals of differing composition in contact with one another in the presence of water or water vapor are vulnerable to corrosion. Corrosion is predictable. For example, when copper electrical wire contacts a steel screw, the more chemically active metal corrodes. Corrosion increases as the salinity of the water increases.

Table 8-2. Summary of Specific Humidity Readings (grains per pound)

Property	Outside	Crawlspace	Inside (1st Floor)	Inside (2nd Floor)	Inside (3rd Floor)
Residence at Elysian Fields	102.2	119.0	115.5	-	-
Residence at General Diaz Street	127.6	133.0	145.2	-	-
Residence at Memphis Street	112.2	-	132.0	138.6	153.3
Residence at Savoie Court	80.6	-	85.8	-	-
Residence at Cleary Avenue	91.2	-	100.8	-	-

Figure 8-14.
Kitchen cabinet doors above the flood level were damaged from the excessive moisture in the house from long-duration flooding.

8.4.1.2 Damage Observations and Flood Resistance of Building Materials in the New Orleans Area

Floodwater damage to specific building materials depends on a variety of factors, including the depth, velocity, and composition of the floodwater, and the type, design, age, and construction methods of the building materials. For vulnerable building materials, flood damage is typically a progressive condition (the longer materials remain wet, the greater the damage that occurs). Some floodprone materials reach a point-of-no-return when exposed to floodwaters, after which salvage attempts are futile. Examples of such floodprone materials include laminated wood products used for interior doors and cabinets, which will swell and deteriorate, and hardwood flooring, which will warp. A summary of typical building materials observed in New Orleans and their basic flood resistance is described in the bullets that follow.

- **Exterior walls.** Many of the exterior walls in residential buildings observed in New Orleans were constructed of brick veneer or stone, which are durable porous materials that are resistant to flooding damage and can frequently be cleaned with minimal difficulty. Other observed exterior wall materials that can frequently be washed and cleaned included other durable porous surfaces, such as engineered stone and stucco, and nonporous surfaces, such as vinyl and aluminum siding.

- **Wood framing.** Of the available wood products, solid dimensional lumber is typically the most resistant to water, while materials made from chips or oriented strands of wood are most vulnerable due to additional points for moisture intrusion. Laminated plied materials, such as exterior-grade plywood with waterproof adhesives, are reasonably water-resistant. Other materials, such as OSB, are less water-resistant. Some wood products are pressure-treated with chemical agents that resist microbial attack and can improve flood resistance.

  When moisture content in various wood products was measured and compared in one New Orleans residence, the moisture content in the OSB was twice as high as in the pressure-treated plywood even though the plywood was the lowest course of sheathing and the OSB sheathing course was located above it. The Flood Team observations indicate that:

1. If not permitted to adequately dry, OSB retains moisture longer, and can be more vulnerable to microbial attack, than plywood.
2. OSB requires either extended drying periods when drying naturally or higher capacity drying equipment when structural drying is performed mechanically.

Visual observations of interior walls and floors of various residential buildings and critical and essential facilities showed little to no evidence of deterioration of the exposed portions of the wood framing due to long-duration flood exposure, except for some water staining and slight bowing of some sheathing boards in residential buildings. Visible fungal growth was noticeable when inspecting the wood in the crawlspaces under several residential buildings; however, some of the growth appears to have existed prior to the flood.

- **Insulating materials.** Typical insulating materials are fibrous and need to be replaced after being impacted by floodwaters. A variety of insulating materials were found within residential buildings in New Orleans. While older dwellings had no insulation or mineral wool insulation, the predominant insulating material found in one- and two-family dwellings was paper-faced fiberglass insulation. After the floodwaters receded, flooded fiberglass insulation retained water, and the moisture "wicked" farther up into the paper due to capillary action.
- **Interior wall materials.** The most common interior wall material observed in newer New Orleans residences was drywall. Drywall (gypsum board) consists of gypsum sandwiched between paper layers. In residential buildings that were more than 50 years old, drywall and/or thin coats of plaster were layered over the original lath and plaster walls. When flooded, drywall is typically subject to deterioration by softening due to

Specific Humidity and Drying Flooded Buildings

After hurricanes, residents are generally urged to open their buildings to dry out building materials as soon as possible. Relative humidity (which changes according to air temperature) has been used in the past to measure progress and make decisions regarding post-flood building drying. However, relative humidity is an inaccurate measurement and should be abandoned in favor of using specific (or absolute) humidity (which is a measure of the actual moisture content, regardless of temperature). When determining the extent of drying in a building following a flood, temperature and relative humidity readings should be taken inside and outside of the building in order to determine the specific humidity readings inside and outside the building. These readings can be obtained by using tables or charts that convert temperature and relative humidity to specific humidity, or by means of special equipment such as a commercially-available moisture meter.

When the specific humidity inside the building is greater than the specific humidity outside, natural processes such as opening the windows and doors can be used to facilitate drying inside the building. By contrast, when the specific humidity inside the building is less than the specific humidity outside, artificial means such as fans or drying equipment should be used to facilitate drying inside the building. It is important to note that the comparative specific humidity readings outside and inside the building should be taken at about the same time, and that the comparative readings and the moisture reduction methods employed in a given building are subject to change during the course of the drying process.

"wicking" and increased vulnerability to impact damage. Another common interior wall material observed in New Orleans was plaster. Plaster begins as a mixture of dry components that crystallize through chemical reaction when water is added. Plaster is applied in layers to a substrate of wood, metal, or rock lathe. Although plaster typically absorbs less water than drywall, plaster is a dense material, which is slow to dry after wetting.

Observations by the New Orleans Flood Team did not indicate evidence of drywall deterioration from softening due to solvent action. However, both the drywall and the plaster in buildings impacted by floodwaters experienced "wicking," which led to extensive fungal growth and entrapment of floodborne contaminants within the drywall materials (refer to Section 8.4.2 for details).

- **Wall coverings and coatings.** Depending on the source(s) of moisture, wall coverings and coatings can either protect surfaces from moisture intrusion or exacerbate damage by trapping moisture within the materials. Observations of flooded buildings in New Orleans indicated most surfaces covered by common household paints were not resistant to floodwater damage. In addition, wallpaper paste found in some residences was dissolved by floodwaters from solvent action and facilitated widespread fungal growth (refer to Section 8.4.2.2 for details).
- **Interior doors and cabinets.** The majority of interior doors and cabinets observed in New Orleans buildings were constructed of laminated wood products. The water vapor migration that occurred throughout many building interiors caused countless laminated wood passage doors, and cabinet doors and drawers to swell shut (see Figure 8-14).
- **Floors and floor coverings.** Floors and floor coverings observed in New Orleans included bare concrete, hardwood, laminate, carpeting, vinyl tiles, and linoleum. Bare concrete floors found in fire station apparatus bays were typically most resistant to flood damage. By contrast, the long-duration flooding in New Orleans led to warping and buckling of hardwood and laminate flooring from moisture absorption. Vinyl and linoleum floor coverings observed in most buildings did not experience significant damage, except for some tiles in older buildings that were found to be loose or had curled edges; however, the coverings can entrap moisture that could damage the underlying wood sub-floor. Also, many older (pre-1970s) vinyl and linoleum flooring products, such as 9-inch square tiles and adhesives, often contain asbestos.
- **Framing connections.** Metal framing connectors and fasteners observed in the New Orleans buildings did not experience significant long-duration flood damage as a result of corrosion.
- **Utility systems.** As with connections, most plumbing and plastic-encased electrical lines observed in the New Orleans buildings did not experience significant long-duration flood damage as a result of corrosion. However, other flooded utility lines and associated small equipment, such as HVAC ductwork and electrical receptacles, experienced greater flood damage. The New Orleans Flood Team observed furnaces and air conditioning units located in attic spaces, as well as multi-story dwellings where condensing coils were externally elevated and water heaters, furnaces, air conditioners, and laundry rooms were located on upper levels. These measures resulted in a reduction or elimination of damage to the utility equipment and appliances.

8.4.2 Long-Duration Flood Impacts from Contamination

The extent and duration of the flooding that impacted New Orleans following Hurricane Katrina gave rise to numerous questions and concerns regarding hazardous materials that might have been present in the floodwaters. In an effort to address these questions and concerns, the U.S. Environmental Protection Agency (USEPA), in cooperation with the Louisiana and Mississippi Departments of Environmental Quality, the USGS, and NOAA, mobilized a coordinated effort to sample standing floodwater remaining in the impacted area as well as sediments and air.

According to the USEPA website (http://www.epa.gov/katrina/testresults/katrina_env_assessment_summary.htm), the USEPA collected the following samples and obtained the following results:

- **Floodwater samples.** Floodwaters in the east bank of the Greater New Orleans area were extensively tested. Nearly 400 water samples were collected by the Louisiana Department of Environmental Quality (LDEQ) and USEPA to represent the flooded areas and floodwaters from these areas that were pumped to Lake Pontchartrain when the areas were dewatered. Each of these samples was analyzed for nearly 200 chemicals and fecal coliform bacteria. The results indicated average concentrations of chemicals were below levels of concern for short-term (i.e., 90 days) dermal contact and incidental ingestion. However, numerous floodwater samples revealed elevated bacteria levels from floodwaters that had mixed with sewage collection system waters. According to the USEPA, the remaining floodwaters were removed from the New Orleans area on October 11, 2005, and thus no longer served as a source of exposure to residents returning to impacted areas.
- **Sediment samples.** From September 10 through October 14, 2005, USEPA collected sediment samples at 430 sites in the streets and public areas of Jefferson, Orleans, Plaquemines, and St. Bernard Parishes. The USEPA's sampling procedures specified that efforts were to be made to bias the samples toward areas that were more likely to contain elevated levels of contamination such as areas that contained oily sediments. Each sample was tested for fecal coliform bacteria and about 200 different chemicals, including volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), metals, pesticides, herbicides, polychlorinated biphenyls (PCBs), and hydrocarbons. The results indicated that a variety of chemicals were detected in the sediments. The most frequently detected chemicals included some metals, hydrocarbons, and, to a lesser extent, pesticides. These levels are consistent with the results that would be expected in a densely populated urban area and are similar to the historical levels found in these parishes before Katrina, and to other urban areas throughout the nation. The majority of chemicals detected were below levels of health concern. However, there were some localized areas with levels of arsenic and petroleum hydrocarbons that exceeded both LDEQ's Risk Evaluation/Corrective Action Program (RECAP) and USEPA's risk criteria (e.g., range of 1 in 1,000,000 to 1 in 10,000 risk of an individual developing cancer over a lifetime), based on long-term (30 years) residential exposure assumptions. The levels of fecal coliform bacteria and petroleum hydrocarbons in the sediments also exceeded health screening values; however, these levels are expected to naturally decrease over time. Subsequent data from samples collected in November 2005 indicate that the highest arsenic concentrations were found in samples taken from golf courses and are associated with herbicides. Composite samples collected in February 2006 indicate that the elevated arsenic detections not on golf courses were isolated and not indicative of larger areas of contamination that might pose a chronic health risk.

- **Air samples.** LDEQ and USEPA conducted extensive air sampling in the areas impacted by Hurricane Katrina. All of the results collected to date for ambient air quality samples appear to be typical for this region of the state, and are below any levels of health concern.

In an effort to determine if contaminants were present in structures after the floodwaters receded, seven residential structures and two critical and essential facilities (fire stations) were visually inspected and samples were collected. The focus of the site inspections for the New Orleans Flood Team was to assess and evaluate opportunities for flood restoration; the sampling was not intended to be statistically representative of contamination in the impacted area. Sample collection was limited to public buildings or structures where permission had been granted by the owners. Wherever possible, a sample of flood residue in the form of wet sludge or dried sediment was collected from inside the structure (see Figure 8-15). Additional samples, primarily of wall materials, were also collected. An effort was made to collect samples of materials from below the water line and comparison samples from above the water line (see Figure 8-16). See Appendix I for a detailed description of sampling and analytical methods.

Figure 8-15.
Flood residue and buckled floor observed on General Diaz Street. A sample of the flood residue was collected for analysis.

Figure 8-16.
Samples were collected from wall materials both above and below the waterline as shown on this wall of a house on Memphis Street. Where practical, samples were collected from surfaces that were already substantially damaged or scheduled for tear-out.

Analytical parameters were chosen following a review of the USEPA floodwater and sediment contaminant data from the New Orleans area. Unless the sample volume was insufficient to support multiple analyses, each sample was subjected to the following analyses:

Biological Contaminants

- **Bacteria.** Overall quantification and breakdown by Gram Negative and Gram Positive types. Refer to Section 8.4.2.1 for details.
- **Fungal.** Identification of fungal (mold) materials. Refer to Section 8.4.2.2 for details.

Chemical Contaminants

- **Heavy metals.** Thirteen EPA and Occupational Safety and Health Administration (OSHA) priority element pollutants as described in the Clean Water Act. Refer to Section 8.4.2.3 for details.
- Diesel range organics (DROs) that were likely to be left after the floodwaters had receded and evaporation had taken place. Refer to Section 8.4.2.4 for details.
- **Pesticides.** Organochlorine compounds that were less likely to be diluted than the water soluble organophosphates that are used today. Refer to Section 8.4.2.5 for details.
- **PCBs.** Polychlorinated biphenyls are persistent chemicals that were often used in transformer oils and in other industrial processes. Refer to Section 8.4.2.6 for details.

A total of 9 water/sludge samples and 38 wall material samples were collected for analysis. Table 8-3 presents an overall review of the samples that were collected, as well as significant highlights of the test results related to each building. A review of the sample results indicated the biological and chemical contaminant levels were consistent with the USEPA's floodwater and sediment sample results. Refer to the USEPA website for details (http://www.epa.gov/katrina/testresults/katrina_env_assessment_summary.htm). Details on each of the biological and chemical parameters tested are provided in Sections 8.4.2.1 through 8.4.2.6. The detailed sample results, including an interpretive summary chart with critical information related to each type of analytical data, laboratory quality control information, and notes regarding any limitations on the sample information, are also presented in Appendix I.

Table 8-3. Highlights of the Biological and Chemical Contaminant Sampling Results

Building Sampled	Number of Samples	Highlights
Residence at Elysian Fields	Eight samples were collected from inside and outside the house. There was sufficient sample volume for all of the samples to be analyzed for all six contaminant types noted on the previous page. However, one sludge sample was too wet for mold analysis.	1. Extremely high levels of bacterial contamination in most water-impacted areas. 2. Significant mold contamination on wall materials above the water line. *Chaetomium* is the dominant fungal type in samples both above and below the water line. *Chaetomium* also recovered from unimpacted second floor. 3. Above average levels of arsenic, beryllium, cadmium, chromium, copper, lead, nickel, selenium, silver, and zinc in interior and exterior samples. 4. Average levels of DROs in the flood damaged areas, with above average levels in the exterior dry sludge. 5. Above average levels of DDT and heptachlor. 6. No detectable levels of PCBs.
Residence at General Diaz Street	Four samples were collected from inside the structure. One wall sample was not large enough for the mercury, DROs, pesticides, or PCBs analyses to be completed. Also, the sludge sample was too wet for mold analysis.	1. Extremely high levels of bacterial contamination in all water-impacted areas. 2. Significant mold contamination on wall materials above the water line. Limited mold growth from samples below the water line. *Aspergillus/ Penicillium* and *Chaetomium* flourishing above the water line. 3. Above average levels of arsenic and nickel in interior wet sludge sample, and above average level of beryllium in wall sample above water line. 4. Above average levels of DROs. 5. Above average levels of chlordane, DDT, dieldrin, and heptachlor. 6. No detectable levels of PCBs.
Residence at Memphis Street	Four samples were collected from inside the structure. Two wall samples were not large enough for the DROs, pesticides, or PCBs analyses to be completed.	1. Moderate to extremely high levels of bacterial contamination in all water-impacted areas. 2. Mold contamination present in dry sludge and wall samples above and below the water line. *Aspergillus / Penicillium* and *Chaetomium* dominate samples above the water line, but also the wood stud samples below the water line. *Stachybotrys* present in the sludge. 3. Above average levels of arsenic, beryllium, cadmium, chromium, copper, lead, selenium, silver, and zinc in interior dry sludge sample. 4. Below average levels of DROs. 5. No detectable levels of pesticides. 6. No detectable levels of PCBs.

Table 8-3. Highlights of the Biological and Chemical Contaminant Sampling Results (continued)

Building Sampled	Number of Samples	Highlights
Residence at Savoie Court	Nine samples were collected from inside the structure. Four wall samples were not large enough for heavy metals, DROs, pesticides, or PCBs analyses to be completed.	1. Extremely high levels of bacterial contamination in the majority of samples. 2. Significant mold contamination on all samples. *Aspergillus/Penicillium* and *Chaetomium* dominate samples from both above and below the water line. 3. Average to below average levels of most heavy metals. 4. Below average levels of DROs. 5. Generally average levels of pesticides, except for an above average level of dieldrin in a wall sample above the water line. 6. No detectable levels of PCBs.
Residence at Munster Boulevard	Three samples were collected from inside and outside the structure. The sludge sample was too wet for mold analysis.	1. Extensive to extremely high levels of bacterial contamination in all water-impacted areas. 2. Significant mold contamination on the wall below the water line and the exterior sludge. *Stachybotrys* in both sludge and wall material, below the water line. 3. Above average levels of beryllium in the exterior dry sludge sample. 4. Average to below average levels of DROs. 5. Below average levels of pesticides in the interior and exterior samples. 6. No detectable levels of PCBs.
Residence at Cleary Avenue	Nine samples were collected from inside the structure. Three samples were not large enough for the DROs, pesticides, or PCBs analyses to be completed, and one sample was not large enough for heavy metals analysis.	1. Extensive to extremely high levels of bacterial contamination in most samples. 2. Significant mold contamination in wall samples above and below the water line. Substantial mold with *Stachybotrys* on both sides of the drywall and studs above the water line. 3. Average levels of most heavy metals. 4. Below average levels of DROs. 5. Below average levels of pesticides. 6. No detectable levels of PCBs.
Residence at Octavia Street	Four samples were collected from inside the structure.	1. Extremely high levels of bacterial contamination in all water-impacted areas. 2. Significant mold contamination. *Aspergillus/ Penicillium* and *Chaetomium* dominates three of the four interior wall material samples. 3. Above average levels of mercury in wall material above the water line. 4. Average levels of DROs. 5. Above average levels of chlordane and DDT in the drywall. 6. No detectable levels of PCBs.

Table 8-3. Highlights of the Biological and Chemical Contaminant Sampling Results (continued)

Building Sampled	Number of Samples	Highlights
Fire station at Louisiana Avenue	Three samples were collected from inside the structure. One wall sample was not large enough for DROs, pesticides, or PCBs analyses to be completed.	1. Extensive to extremely high levels of bacterial contamination in all water-impacted areas. 2. Significant mold contamination. *Chaetomium* in samples both above and below the water line. 3. Above average levels of arsenic, cadmium, chromium, copper, lead, silver, and zinc in dry sludge sample. Generally below average levels of heavy metals detected in the drywall samples. 4. Average levels of DROs. 5. Above average levels of chlordane in the drywall. 6. No detectable levels of PCBs.
Fire station at South Carrollton Avenue	Three samples were collected from inside the structure. One sample was not large enough for the DROs, pesticides, or PCBs analyses to be completed.	1. Extensive to extremely high levels of bacteria contamination in all water-impacted areas. 2. Significant mold contamination. *Stachybotrys* found in sludge and wall materials below the water line. 3. Above average levels of antimony, arsenic, cadmium, chromium, copper, lead, nickel, silver, and zinc. 4. Below average levels of DROs. 5. Below average levels of chlordane. 6. No detectable levels of PCBs.

8.4.2.1 Bacterial Contamination

Floodwaters carry biological contamination in the form of bacteria, viruses, and parasites. Bacteria are one-celled microorganisms that are invisible to the naked eye. Following flooding, they are the first microorganisms to multiply. Bacteria pose a significant post-flood health threat. Some bacteria produce poisonous toxins that can cause diseases such as lockjaw and food poisoning in humans. Other bacteria produce enzymes that dissolve or destroy living cells, thereby damaging commercial goods and fouling surfaces. Also, bacterial growth on food and food handling equipment is a major source of disease.

A total of 47 material samples and 1 floodwater sample taken from nine buildings were analyzed for bacterial growth. Bacteria levels ranged from undetectable to “overloaded,” which is reported as 456,000 colony forming units per square centimeter (cfu/cm^2). The majority of bacteria identified in the samples were *Gram Negative Bacilli.* Samples dominated by this bacteria type generally indicate contact with sewage or animal feces. The results are summarized in Table 8-4.

Table 8-4. Total Bacteria Contamination Levels (cfu/cm²) by Materials and Moisture Level

Building	Range of Values	Wet Sludge	Dry Sludge	Wall Materials Below Water Line	Wall Materials Above Water Line
Residence at Elysian Fields	Maximum	40,600	1,200	41,346	456,000
	Minimum	40,600	1,200	7,460	BMDL
	Average	40,600	1,200	22,420	234,334
Residence at General Diaz Street	Maximum	64,900	No Sample	183,000	41,500
	Minimum	64,900		20,200	41,500
	Average	64,900		101,600	41,500
Residence at Memphis Street	Maximum	No Sample	590	381,000	544
	Minimum		590	381,000	544
	Average		590	381,000	544
Residence at Savoie Court	Maximum	No Sample	No Sample	233,000	242,000
	Minimum			BMDL	27,000
	Average			90,000	134,500
Residence at Munster Boulevard	Maximum	7,020	4,860	456,000	No Sample
	Minimum	7,020	4,860	456,000	
	Average	7,020	4,860	456,000	
Residence at Cleary Avenue	Maximum	No Sample	8,280	404,000	350,000
	Minimum		8,280	BMDL	BMDL
	Average		8,280	138,500	98,483
Residence at Octavia Street	Maximum	No Sample	No Sample	251,000	456,000
	Minimum			251,000	168,000
	Average			251,000	312,667
Fire station at Louisiana Avenue	Maximum	No Sample	3,690	327,000	156,000
	Minimum		3,690	327,000	156,000
	Average		3,690	327,000	156,000
Fire station at South Carrollton Avenue	Maximum	No Sample	2,460	23,600	6,130
	Minimum		2,460	23,600	6,130
	Average		2,460	23,600	6,130

For cultural bacterial swab sample results:

- (white) Below the method detection limit (BMDL) is less than 18 cfu/cm².
- (yellow) Moderate is between 18 cfu/cm² and 1,000 cfu/cm².
- (orange) Extensive is between 1,001 cfu/cm² and 20,000 cfu/cm².
- (red) Extremely high is greater than 20,000 cfu/cm².

A number of patterns were observed in the bacterial sampling data. The strongest correlation was seen between wet materials and bacterial growth. Since most bacteria need a warm, moist environment to proliferate, the connection between elevated moisture levels and higher bacteria levels was expected. Table 8-4 shows that, for the two facilities where both wet and dry flood residues were sampled, bacteria levels were higher in the wet sludge as compared to dry sludge. Similarly, with one exception (Elysian Fields residence), bacteria levels from the same wall were significantly higher in the samples of drywall collected from below the waterline as compared to samples collected from a level above the floodwater line.

As might be expected, only low levels of bacteria were identified in samples collected from relatively dry materials. Negligible levels were detected in samples collected from the unimpacted second floor at the Elysian Fields residence and in the drier materials in the Cleary Avenue and Memphis Street residences.

Bacteria levels were relatively high on the outer surface of exposed wooden studs. The sample results on the studs were consistent with those from the drywall with *Gram Negative Bacilli* dominating the results (samples 6379-16, 6379-21, and 6379-37).

Bacterial growth appeared to be inhibited by fungal growth in numerous areas. Rampant fungal growth on the damp carpet and wallpaper in the living room of the Savoie Court residence may well account for the fact that bacteria were not detected in those areas (see Table 8-4). Bacterial levels were also very low in the samples of visible fungal growth that were scraped from the carpet and a dresser leg in the Savoie Court residence (samples 6379-18, 6379-19, 6379-24, and 6379-25) (see Figure 8-17).

Figure 8-17.
Bacteria levels were frequently found to be significantly lower in areas with rampant fungal growth. This pattern held true at the residence on Savoie Court, where fungal levels were extensive on the dresser and carpet near the door frame while the bacteria levels were negligible at these same locations.

8.4.2.2 Fungal Contamination (Mold)

Fungi feed on either living or dead organisms by absorbing nutrients from the environment around them. Fungi accomplish this by growing through and within a host substrate. Fungal growth and contamination is a secondary health risk following flooding; the floodwater acts as a source of moisture, "wicking" into materials by capillary action, and stimulating fungal growth. The presence of fungi can cause allergic reactions, athlete's foot, ringworm, and infections of the skin and nails.

A total of 44 material samples taken from 9 facilities were analyzed for fungal contamination. In most cases, the fungal types were dominated by *Aspergillus/Penicillium* or *Chaetomium.* These mold types are frequently found as initial and secondary colonizers of water-impacted building materials. Various strains of *Aspergillus/Penicillium* and *Chaetomium* are linked to significant health problems. In addition to *Chaetomium,* a number of other mold types that are indicative of substantial water damage were detected. These included *Stachybotrys* and *Memnoniella,* which are also associated with serious health symptoms. Results are shown in Table 8-5.

Table 8-5. Summary of Fungal Sampling Data

Building Site	Sample Location	Indicator Organisms	Common Organisms	Target Organisms	Hyphae
Residence at Elysian Fields	Dry Sludge	No (1/1)	Yes (2/1)	No (1/1)	Yes (1/1)
	Wall Materials Below Water Line	No (3/3)	Yes (2/3)	Yes (1/3)	Yes (2/3)
	Wall Materials Above Water Line	Yes (1/3)	Yes (4/3)	Yes (3/3)	Yes (2/3)
Residence at General Diaz Street	Dry Sludge	No Sample			
	Wall Materials Below Water Line	No (2/2)	Yes (2/2)	No (2/2)	No (2/2)
	Wall Materials Above Water Line	Yes (1/1)	Yes (4/1)	Yes (1/1)	Yes (1/1)
Residence at Memphis Street	Dry Sludge	Yes (1/1)	Yes (1/1)	Yes (2/1)	Yes (1/1)
	Wall Materials Below Water Line	Yes (1/2)	Yes (1/2)	Yes (1/2)	Yes (1/2)
	Wall Materials Above Water Line	Yes (1/1)	No (1/1)	No (1/1)	No (1/1)
Residence at Savoie Court	Dry Sludge	No Sample			
	Wall Materials Below Water Line	Yes (3/3)	Yes (1/3)	Yes (3/3)	Yes (3/3)
	Wall Materials Above Water Line	Yes (2/2)	Yes (1/2)	Yes (1/2)	Yes (1/2)
Residence at Munster Boulevard	Dry Sludge	Yes (1/1)	Yes (5/1)	Yes (1/1)	Yes (1/1)
	Wall Materials Below Water Line	No (1/1)	No (1/1)	Yes (2/1)	Yes (1/1)
	Wall Materials Above Water Line	No Sample			

Table 8-5. Summary of Fungal Sampling Data (continued)

Building Site	Sample Location	Indicator Organisms	Common Organisms	Target Organisms	Hyphae
Residence at Cleary Avenue	Dry Sludge	No (1/1)	Yes (4/1)	No (1/1)	No (1/1)
	Wall Materials Below Water Line	Yes (3/3)	Yes (1/3)	Yes (1/3)	Yes (3/3)
	Wall Materials Above Water Line	Yes (4/4)	Yes (7/4)	Yes (2/4)	Yes (3/4)
Residence at Octavia Street	Dry Sludge	No Sample			
	Wall Materials Below Water Line	No (1/1)	No (1/1)	Yes (1/1)	Yes (1/1)
	Wall Materials Above Water Line	Yes (3/3)	Yes (5/3)	Yes (2/3)	Yes (1/3)
Fire station at Louisiana Avenue	Dry Sludge	No (1/1)	Yes (3/1)	No (1/1)	Yes (1/1)
	Wall Materials Below Water Line	Yes (1/1)	Yes (1/1)	Yes (1/1)	Yes (1/1)
	Wall Materials Above Water Line	Yes (1/1)	No (1/1)	Yes (2/1)	Yes (1/1)
Fire station at South Carrollton Avenue	Dry Sludge	No (1/1)	Yes (1/1)	Yes (2/1)	Yes (1/1)
	Wall Materials Below Water Line	No (1/1)	Yes (1/1)	Yes (1/1)	Yes (1/1)
	Wall Materials Above Water Line	No (1/1)	No (1/1)	No (1/1)	No (1/1)
Totals	Dry Sludge	Yes (2/6)	Yes (16/6)	Yes (5/6)	Yes (5/6)
	Wall Materials Below Water Line	Yes (8/17)	Yes (9/17)	Yes (11/17)	Yes (13/17)
	Wall Materials Above Water Line	Yes (13/16)	Yes (21/16)	Yes (11/16)	Yes (9/17)

For fungal bulk sample results:

No (#/#)	No Organisms Detected (# of # samples)
Yes (#/#)	Indicator Organisms associated with potentially significant health problems detected = *Aspergillus/ Penicillum* (# of indicator organisms detected in # of total samples)
Yes (#/#)	Common Organisms associated with minor health problems/ allergies, including *Ascospore, Basidiospore, Cladosporium, Culvaria, Epicoccum, Fusarium, Myxomycete, Nigospora, Periconia* and *Smut* (# of different common organisms detected in # of total samples)
Yes (#/#)	Target Organisms associated with potentially serious health problems detected; which include *Chaetomium, Fusarium, Memnomiella, Stachybotrys* and *Trichoderma* (# of different target organisms detected in # of total samples)
Yes (#/#)	Hyphae: growth structures in addition to spores detected (# of hyphae detected in # of total samples)
Yes (#/#)	Spores

Substantial fungal contamination was observed in all of the inspected facilities. In the majority of inspected structures, fungal growth was observed to be more vigorous on porous contents

Figure 8-18.
Prolific mold growth was seen on porous contents in most inspected buildings.

Figure 8-19.
The mold growth on the walls was generally much more vigorous above the floodwater level than below it. Sediments, heavy metal contamination, and oil film residue, as well as material moisture content and lack of exposure to air during flooding, may contribute to minimizing the fungal growth on the saturated wall materials.

(see Figures 8-18 and 8-19) and porous wall finishes above the water line as compared to wall materials below the water line. In several houses, the fungal growth was rampant on surfaces high enough above the water line to suggest that the growth was supported by high humidity levels and/or condensation as compared to water "wicking" (see Figure 8-20). This was especially evident in the residence on Savoie Court, where the water level only reached approximately 18 inches above the floor. Even so, mold growth in this structure was extensive in many rooms extending all the way to the ceiling (see Figure 8-21). In addition, minor visible mold growth was observed on the concealed side of the drywall on the majority of the wall samples taken, even

Figure 8-20.
In many buildings, the mold growth above the waterline appears to have been fueled by condensation of moisture in addition to water "wicking." The upper cabinets and kitchen ceiling in the building on General Diaz Street were well above the floodwater line, yet showed extensive fungal growth.

Figure 8-21.
On Savoie Court, fungal growth was observed up to the ceiling on some walls, despite the fact that floodwaters only reached up 18-24 inches. This wall showed thick mold growth both above and below the high water mark.

for samples where the exposed surface was covered with mold. However, sample results of materials inside the wall cavities confirmed the presence of fungal contamination inside the wall as well as on the exposed surfaces.

Fungal contamination was typically observed above the high water mark and was generally absent or significantly less vigorous below it. There is evidence in the technical literature that the dirt and sediment, which is present in the building materials after being saturated by floodwater, discourages fungal growth. Fungal growth may also have been discouraged below the high water mark by some of the residual contaminants in the wall materials, including pesticides and heavy metals, which are documented to have antifungal properties.

8.4.2.3 Heavy Metals

Heavy metals such as lead and mercury are natural components of the Earth's crust that cannot be degraded or destroyed. Heavy metals can be introduced into the water supply through industrial and consumer waste, or from acid rain breaking down soils and releasing heavy metals into lakes, rivers, and groundwater. These heavy metals can then be carried by floodwaters and spread over a wide area.

Thirty-six material and eight sludge samples collected from nine buildings were analyzed for the following 13 heavy metals: antimony, arsenic, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium, and zinc. Because mercury is subject to a different analytical technique than the other metals, there was only enough sample volume in 40 of the samples to provide a reading for mercury. A summary of the maximum levels of heavy metals evaluated during the analysis of the samples collected from the New Orleans area is shown in Table 8-6.

The results of Table 8-6 indicate the following:

- Levels of arsenic exceeded the 250 percent of the mean (average) values in a majority of the buildings sampled.
- Levels of beryllium, cadmium, chromium, copper, lead, nickel, silver, and zinc exceeded the 250 percent of the average values in three or more of the buildings sampled.
- Levels of antimony, selenium, silver, and thallium were below the method detection limit (BMDL) in a majority of the buildings sampled.

The highest concentrations of heavy metals were typically encountered in the wet and dry sludge samples than in the wall materials. However, it is important to note that the number of available sludge sample results was relatively low compared to the number of available wall sample results. In addition, concentrations of heavy metals appeared to be higher in buildings located closer to Lake Pontchartrain and lower in buildings located farther away from the Lake Pontchartrain. These results suggest that the some of the heavy metal contaminants came from Lake Pontchartrain floodwater.

Heavy metals typically enter the human body via ingestion and inhalation. As trace elements, some heavy metals (e.g., copper, selenium, and zinc) are essential to maintain the metabolism of the human body. However, at higher concentrations, they can lead to poisoning. Heavy metals are particularly dangerous as they tend to bioaccumulate. Bioaccumulation means an increase in the concentration of a chemical in a biological organism over time, compared to the chemical's concentration in the environment. Compounds accumulate in living things any time they are taken up and stored faster than they are broken down (metabolized) or excreted. Cadmium, lead, and mercury are considered toxic heavy metals. Exposure to high levels of heavy metals identified in Table 8-6 can have the following adverse health effects:

- **Antimony:** Exposure to high levels of antimony for short periods of time causes nausea, vomiting, and diarrhea. There is little information on the effects of long-term antimony exposure.
- **Arsenic:** Acute (short-term) arsenic poisoning may cause nausea, vomiting, diarrhea, weakness, loss of appetite, shaking, cough, and headache. Chronic (long-term) exposure may lead to a variety of symptoms, including skin pigmentation, numbness, cardiovascular disease, diabetes, and vascular disease. Arsenic is also known to cause a variety of cancers, including skin cancer (non-melanoma type), kidney, bladder, lung, prostate, and liver cancer.
- **Cadmium:** Long-term exposure to cadmium is associated with renal dysfunction. High exposure may lead to obstructive lung disease and has been linked to lung cancer, although data concerning the latter are difficult to interpret due to compounding factors. Cadmium may also produce bone defects (osteomalacia, osteoporosis) in humans and animals.
- **Chromium:** Low-level exposure to chromium can irritate the skin and cause ulceration. Long-term exposure can cause kidney and liver damage, and damage circulatory and nerve tissue.
- **Copper:** Although copper is an essential substance to human life, in high doses it can cause anemia, liver, and kidney damage, and stomach and intestinal irritation. People with certain illnesses such as Wilson's disease are at greater risk for health effects from overexposure to copper.
- **Lead:** Exposure to lead can result in a wide range of biological effects depending on the level and duration of exposure. Various effects occur over a broad range of doses, with infants and children being more sensitive than adults. High levels of lead exposure may result in toxic biochemical effects in humans, which, in turn, cause problems in the synthesis of hemoglobin, effects on the kidneys, gastrointestinal tract, joints and reproductive system, and acute or chronic damage to the nervous system.
- **Mercury:** Mercury is a toxic substance that has no known function in human biochemistry or physiology and does not occur naturally in living organisms. Inorganic mercury poisoning is associated with tremors, gingivitis, and/or minor psychological changes. Natural biological processes can cause methylated forms of mercury to form and bioaccumulate over a million-fold and concentrate in living organisms, especially fish. These forms of mercury are highly toxic, causing neurotoxicological disorders. The main pathway for mercury to humans is through ingestion and not inhalation.
- **Zinc:** Ingestion of high doses of zinc in a short period of time can lead to adverse health effects, such as stomach cramps, nausea, and vomiting. Long-term health impacts of

ingesting large amounts of zinc can include anemia, nervous system disorders, damage to the pancreas, and lowered levels of "good" cholesterol.

8.4.2.4 Hydrocarbon Contamination

Petroleum products such as motor fuels and lubricants enter floodwaters when storage tanks and vehicles overturn or are covered by floodwaters. Petroleum products dispersed by rapidly moving floodwaters dissolve into the water column and, due to the density of the petroleum fractions, float on the water surface and, as floodwaters recede, insoluble petroleum products floating on the water's surface frequently leave a film on building materials. These petroleum products are sticky and can attract particulates.

According to the Centers for Disease Control and Prevention (CDC), prolonged dermal contact with petroleum hydrocarbons can cause skin erythema (reddening), edema, and burning. The skin effects can be exacerbated by subsequent exposure to sunlight from the phototoxicity of trace contaminants in the oil. Human epidemiological studies have shown that high-dose, chronic, and occupational exposure to mineral oils may cause skin cancer.

Material samples were analyzed for DROs. These hydrocarbon compounds are the less volatile fractions of petroleum and, therefore, are less likely to have evaporated during the course of the 4 weeks that passed between the time of the initial flooding and the field investigation by the New Orleans Flood Team.

Of the 47 samples, 35 had enough collected material for an appropriate analysis. Over 95 percent of the analyzed sludge and wall material samples had quantities of DROs that exceeded the method detection limit of 18,000 µg/kg of hydrocarbons. As shown in Table 8-7, the sample levels ranged from 18,000 to 3,100,000 µg/kg. The highest concentrations were found in wallpaper and wall material samples above the water line.

Table 8-6. Summary of Maximum Levels Sampled for Heavy Metal Contamination (µg/kg)

Building	Element	Antimony	Arsenic	Beryllium	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Selenium	Silver	Thallium	Zinc
	Mean (Average) Value**	12,337	6,787	226	3,491	9,362	31,263	62,690	1,190	14,340	1,109	157	169	1,373,191
Residence at Elysian Fields	Wet Sludge	650	17,000	850	42,000	25,000	81,000	130,000	260	130,000	14,000	BMDL	350	4,800,000
	Dry Sludge	BMDL	9,700	1,200	2,400	33,000	64,000	170,000	63	26,000	BMDL	1,200	BMDL	750,000
	Wall Materials Below Water Line	650	17,000	850	42,000	25,000	81,000	130,000	260	14,000	1,800	350	BMDL	4,800,000
	Wall Materials Above Water Line	BMDL	1,900	120	160	4,400	4,800	390	89	26,000	1,800	BMDL	BMDL	11,000
Residence at General Diaz Street	Wet Sludge	BMDL	23,000	430	5,700	14,000	62,000	120,000	BMDL	130,000	BMDL	320	BMDL	2,300,000
	Dry Sludge	No Sample												
	Wall Materials Below Water Line	BMDL	560	BMDL	BMDL	1,400	610	2,500	ISFA	8,100	BMDL	BMDL	BMDL	23,000
	Wall Materials Above Water Line	300	1,100	1,400	BMDL	1,400	540	750	BMDL	8,200	BMDL	BMDL	BMDL	4,000
Residence at Memphis Street	Wet Sludge	No Sample												
	Dry Sludge	2,300	60,000	760	10,000	36,000	220,000	240,000	140	18,000	3,100	870	340	32,000,000
	Wall Materials Below Water Line	370	520	BMDL	76	3,300	820	780	120	7,200	1,300	BMDL	BMDL	28,000
	Wall Materials Above Water Line	BMDL	1,200	150	220	4,800	1,400	780	180	13,000	3,300	BMDL	BMDL	19,000
Residence at Savoie Court	Wet Sludge	No Sample												
	Dry Sludge	No Sample												
	Wall Materials Below Water Line	BMDL	2,500	150	BMDL	3,800	3,200	1,000	70	13,000	BMDL	160	BMDL	26,000
	Wall Materials Above Water Line	BMDL	3,000	110	700	12,000	6,800	4,000	BMDL	6,200	BMDL	BMDL	BMDL	300,000
Residence at Munster Boulevard	Wet Sludge	BMDL	3,200	320	400	5,600	10,000	12,000	BMDL	8,700	590	BMDL	BMDL	62,000
	Dry Sludge	BMDL	8,200	1,100	840	16,000	30,000	35,000	BMDL	26,000	1,800	330	BMDL	170,000
	Wall Materials Below Water Line	BMDL	1,500	BMDL	BMDL	910	590	1,300	120	5,800	BMDL	BMDL	BMDL	18,000
	Wall Materials Above Water Line	No Sample												
Residence at Cleary Avenue	Wet Sludge	No Sample												
	Dry Sludge	Analysis voided due to insufficient sample quantity												
	Wall Materials Below Water Line	BMDL	1,200	270	140	13,000	10,000	47,000	83	8,400	2,000	100	BMDL	31,000
	Wall Materials Above Water Line	BMDL	2,400	BMDL	150	1,800	12,000	2,000	160	8,700	2,100	110	BMDL	12,000

Table 8-6. Summary of Maximum Levels Sampled for Heavy Metal Contamination (µg/kg) (continued)

Building	Element	Antimony	Arsenic	Beryllium	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Selenium	Silver	Thallium	Zinc
	Mean (Average) Value**	12,337	6,787	226	3,491	9,362	31,263	62,690	1,190	14,340	1,109	157	169	1,373,191
Residence at Octavia Street	Wet Sludge	No Sample												
	Dry Sludge	No Sample												
	Wall Materials Below Water Line	BMDL	290	BMDL	54	5,600	1,300	25,000	10,000	BMDL	BMDL	BMDL	BMDL	74,000
	Wall Materials Above Water Line	BMDL	1,400	180	670	16,000	8,800	34,000	32,000	7,300	BMDL	100	BMDL	210,000
Fire station at Louisiana Avenue	Wet Sludge	No Sample												
	Dry Sludge	11,000	45,000	110	22,000	24,000	200,000	1,300,000	470	13,000	1,000	890	330	5,400,000
	Wall Materials Below Water Line	470	2,700	BMDL	200	2,600	4,200	7,400	BMDL	8,300	BMDL	BMDL	BMDL	180,000
	Wall Materials Above Water Line	BMDL	2,100	110	53	1,900	1,300	2,300	BMDL	7,700	800	BMDL	430	9,800
Fire station at South Carroll-ton Avenue	Wet Sludge	No Sample												
	Dry Sludge	330,000	81,000	310	24,000	100,000	490,000	390,000	1,600	44,000	BMDL	740	BMDL	8,500,000
	Wall Materials Below Water Line	BMDL	730	140	60	3,300	1,600	2,400	93	7,300	BMDL	BMDL	BMDL	9,800
	Wall Materials Above Water Line	BMDL	1,000	BMDL	BMDL	2,500	930	3,600	65	8,400	BMDL	BMDL	BMDL	6,000

* BMDL = Below minimum detectable limit

Heavy Metal	Antimony	Arsenic	Beryllium	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Selenium	Silver	Thallium	Zinc
Below Method Detection Limit is less than (µg/kg)	300	100	100	50	300	300	200	60	300	500	100	300	300

** The Mean (Average) Value was the statistical average value computed for the 44 heavy metal sample results. When computing the average value, samples with BMDL values were assumed to have a value equal to 1/2 the BMDL detection limit in accordance with USEPA standard practice.

White	Values are BMDL or less than 10% of the mean value.
Yellow	Values are greater than minimal but less tha 50% of themean value.
Orange	Values are greaten than 50% but less than 250% of the mean value.
Red	Values are greater than 250% of the mean value.

Table 8-7. Hydrocarbon Contamination - Diesel Range Organics (µg/kg)

Building	Range of Values	Wet Sludge	Dry Sludge	Wall Materials Below Water Line	Wall Materials Above Water Line	Mean (Average) Value**
Residence at Elysian Fields	Maximum	85,000	760,000	150,000	650,000	454,143
	Minimum	85,000	760,000	18,000	77,000	
	Average	85,000	760,000	69,333	270,333	
Residence at General Diaz Street	Maximum	130,000	No Sample	110,000	1,200,000	454,143
	Minimum	130,000		110,000	1,200,000	
	Average	130,000		110,000	1,200,000	
Residence at Memphis Street	Maximum	No Sample	ISFA*	230,000	210,000	454,143
	Minimum			ISFA	210,000	
	Average			230,000	210,000	
Residence at Savoie Court	Maximum	No Sample	ISFA	270,000	360,000	454,143
	Minimum			82,000	360,000	
	Average			184,000	360,000	
Residence at Munster Boulevard	Maximum	69,000	520,000	170,000	No Sample	454,143
	Minimum	69,000	520,000	170,000		
	Average	69,000	520,000	170,000		
Residence at Cleary Avenue	Maximum	No Sample	ISFA	450,000	200,000	454,143
	Minimum			190,000	120,000	
	Average			320,000	150,000	
Residence at Octavia Street	Maximum	No Sample	ISFA	990,000	3,100,000	454,143
	Minimum			990,000	980,000	
	Average			990,000	1,860,000	
Fire station at Louisiana Avenue	Maximum	No Sample	No Sample	580,000	220,000	454,143
	Minimum			580,000	220,000	
	Average			580,000	220,000	
Fire station at South Carrollton Avenue	Maximum	No Sample	ISFA	130,000	190,000	454,143
	Minimum			130,000	190,000	
	Average			130,000	190,000	

* ISFA = Insufficient sample for analysis

** The Mean (Average) Value was the statistical average value computed for the 35 DRO sample results

(white)	Values are BMDL or less than 10% of the mean value.
(yellow)	Values are greater than minimal but less than 50% of the mean value.
(orange)	Values are greater than 50% but less than 250% of the mean value.
(red)	Values are greater than 250% of the mean value.

Statistical Sample Values	
BMDL	18,000
10% Mean	45,414
50% Mean	227,071
Mean	454,143
250% Mean	1,135,357
Maximum	3,100,000

8.4.2.5 Pesticide Contamination

Historically, the New Orleans area has suffered damages to many of its buildings from termites. In the past, termite treatment involved applying a barrier of organochlorine pesticides (e.g., chlordane, dichloro-diphenyl-trichloroethane (DDT), dieldrin, and heptachlor) into the soil surrounding the building and to the wooden sills of houses. After drilling holes, the insecticide was diluted with water to form a solution and applied to the soil. Depending on the size of the property, it was not unusual to apply 100 gallons or more of the insecticide solution.

Floodwaters transport both water-soluble and non-water-soluble chemicals. In the case of pesticides, many of the organophosphates that are used today are water soluble, which means that any residue in the soil impacted by the flooding would tend to be diluted by the floodwaters. By contrast, older pesticides, such as DDT and chlordane, were generally organochlorine compounds that are not as water soluble as the newer materials, because they were diluted by oils rather than water. This chemical composition allowed the now banned pesticides to have a longer impact in protecting buildings from termites and other insects, with many such compounds residing in soil for over 20 years without significant loss in concentration. However, this residual effect also allowed the chemicals to build up in the environment, which was a significant rationale for eliminating their use in the United States approximately 18 years ago.

Pesticide residues, such as those found in the building materials of older structures, can cause skin rashes from dermal contact. Inhalation of such residue in demolition dust can lead to a host of problems as many of the substances are neurotoxins. Another significant risk of exposure can occur when individuals involved in the gutting and decontamination fail to wash their hands before eating, since hand to mouth activities have been demonstrated as the source of ingested pesticides. When ingested or absorbed through the skin, organochlorine pesticides affect the nervous system, the digestive system, and the liver in people and animals.

The USEPA floodwater sampling data from New Orleans confirmed the supposition that the newer organophosphate pesticides were diluted by the large volumes of floodwater while the organocholorine pesticides were not. These findings, along with the documented heavy historic use of organocholorine pesticides to control termites in the New Orleans area, led to the concern by the New Orleans Flood Team that these contaminants may have been disturbed during the flooding and carried into buildings. Therefore, 5 of the sludge and 30 of the building material samples collected were screened for organochlorine type pesticides (these samples had enough remaining volume to be analyzed after the other tests had been completed). A summary of the highest levels of pesticides evaluated during the analysis of the samples collected from the New Orleans area is shown in Table 8-8.

Table 8-8. Summary of Maximum Levels Sampled for Pesticides (µg/kg)

		Pesticide	Chlordane	alpha-Chlordane	gamma-Chlordane	DDT	Dieldrin	Heptachlor
Building	Age of Building	Mean (Average) Value**	890	104	146	14.2	14.4	5.5
Residence at Elysian Fields	1940s	Wet Sludge	280	19	11	7	BMDL	13
		Dry Sludge	410	30	14	9	BMDL	16
		Wall Materials Below Water Line	280	19	16	6	BMDL	16
		Wall Materials Above Water Line	810	73	87	78	14	41
Residence at General Diaz Street	1930s	Wet Sludge	190	18	39	40	19	4
		Dry Sludge	No Sample					
		Wall Materials Below Water Line	160	13	10	BMDL	BMDL	BMDL
		Wall Materials Above Water Line	2,100	130	350	35	150	45
Residence at Memphis Street	1990s	Wet Sludge	No Sample					
		Dry Sludge	No Sample					
		Wall Materials Below Water Line	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL
		Wall Materials Above Water Line	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL
Residence at Savoie Court	1960s	Wet Sludge	No Sample					
		Dry Sludge	No Sample					
		Wall Materials Below Water Line	130	18	20	BMDL	10	BMDL
		Wall Materials Above Water Line	1,400	170	220	BMDL	260	BMDL
Residence at Munster Boulevard	1940s	Wet Sludge	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL
		Dry Sludge	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL
		Wall Materials Below Water Line	130	21	24	6	BMDL	BMDL
		Wall Materials Above Water Line	No Sample					
Residence at Cleary Avenue	1990s	Wet Sludge	No Sample					
		Dry Sludge	Analysis voided due to insufficient sample quantity					
		Wall Materials Below Water Line	37	5.0	5.5	BMDL	BMDL	BMDL
		Wall Materials Above Water Line	26	BMDL	BMDL	BMDL	BMDL	BMDL

Table 8-8. Summary of Maximum Levels Sampled for Pesticides (µg/kg) (continued)

		Pesticide	Chlordane	alpha-Chlordane	gamma-Chlordane	DDT	Dieldrin	Heptachlor
Building	Age of Building	Mean (Average) Value**	890	104	146	14.2	14.4	5.5
Residence at Octavia Street	Older	Wet Sludge	No Sample					
		Dry Sludge	No Sample					
		Wall Materials Below Water Line	2,200	220	380	BMDL	BMDL	BMDL
		Wall Materials Above Water Line	1,600	200	240	250	BMDL	BMDL
Fire station at Louisiana Avenue	Older	Wet Sludge	No Sample					
		Dry Sludge	Analysis voided due to insufficient sample quantity					
		Wall Materials Below Water Line	17,000	2,100	2,900	BMDL	BMDL	BMDL
		Wall Materials Above Water Line	1,400	180	260	BMDL	BMDL	BMDL
Fire station at South Carrollton Avenue	1954	Wet Sludge	No Sample					
		Dry Sludge	Analysis voided due to insufficient sample quantity					
		Wall Materials Below Water Line	100	15	18	BMDL	BMDL	BMDL
		Wall Materials Above Water Line	130	13	11	BMDL	BMDL	BMDL

* BMDL = Below minimum detectable limit. For pesticide sample results, BMDL values are summarized below:

Pesticide	Chlordane	alpha-Chlordane	gamma-Chlordane	DDT	Dieldrin	Heptachlor
Below Method Detection Limit is less than (µg/kg)	17	3.3	3.3	3.3	3.3	3.3

** The Mean (Average) Value was the statistical average value computed for the 35 pesticide samples results. When computing the average value, samples with BMDL values were assumed to have a value equal to 1/2 the BMDL detection limit in accordance with USEPA standard practice.

White	Values are BMDL or less than 10% of the mean value.
Yellow	Values are greater than minimal but less than 50% of themean value.
Orange	Values are greater than 50% but less than 250% of the mean value.
Red	Values are greater than 250% of the mean value.

The pesticide results provided in Table 8-8 indicate that six organochlorine pesticides were found in significant quantities: chlordane, alpha-chlordane, gamma-chlordane, DDT, dieldrin, and heptachlor. Other pesticides detected in much smaller quantities and not listed in Table 8-8 include beta-benzene hexachloride (BHC), gamma-BHC, dichloro-diphenyl-dichloroethane (DDD), dichloro-diphenyl-dichloroethylene (DDE), endosulfan II, endosulfan sulfate, endrin ketone, and methoxychlorindicate. Table 8-8 indicates that the highest concentrations of organochlorine pesticides were typically found in wall materials rather than sludge materials. For example, the highest level of chlordane identified in the sludge samples was 410 µg/kg, while the highest level of chlordane identified in the wall material samples was 17,000 µg/kg. In fact, two of the five sludge samples analyzed for organochlorine pesticides were below the method detection limit.

The pesticide contamination results were compared to the estimated age of each building (estimated based on its appearance, construction materials, architectural components, and other details). As shown in Table 8-8, older buildings, which were more likely to have been protected with chlordane and other organocholorine pesticides, had higher levels than newer buildings (post-chlordane). Presumably, the floodwaters released some of the pesticide residues from soils near the buildings. Once the pesticide was in suspension, it would be diluted by the water and transported onto flooded materials.

8.4.2.6 PCB Contamination

Although PCB contamination was anticipated based on the number of transformers and other electrical devices that were submerged or knocked down during the hurricane, no PCBs were detected in the 35 samples that were analyzed for the substance.

No PCBs were detected in any of the 35 samples analyzed for the substance. These findings were not unusual since the use of PCBs was banned by the USEPA in 1979. Also, the findings were consistent with the results of sampling conducted by the USEPA in the New Orleans area following Hurricanes Katrina and Rita.